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ABSTRACT

The author presents an overview of Pascual-Leone's Theory of Constructive Operators, a process-structural theory based upon Piagetian constructs which has evolved to both explain and predict the temporal unfolding of behavior. An application is made of the theory to the demands of a discrete motor task and prediction of (a) the minimal age necessary to integrate the task and (b) individual differences associated with efficient task integration in children above the minimal age. (MJB)

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A neo-Piagetian Theory of Constructive Operators: Applications
to Perceptual-Motor Development and Learning

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Running Head: A neo-Piagetian Theory of Constructive Operators

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ABSTRACT

The learning and developmental aspects of Pascual-Leone's Theory of Constructive Operators ^{GVP} ~~is~~ outlined and ^{their} ~~its~~ application to motor behavior illustrated. Accordingly, cognitive processes are conceived as being organized in two functionally and structurally different, interacting systems. The first level is constituted by situational-specific constructs, organismic schemes, which apply on input to categorize or modify it. As such schemes represent the perceptual, motor, affective and cognitive activities available to a given subject. The second level is constituted by situational-free metaconstructs which by applying on the first level schemes temporarily increase their activation weights. That is, they indirectly shape behavior by influencing which schemes or clusters of schemes apply. The metaconstructs explicated account for affective factors, field factors, content learning, and logic learning. Additionally, a mental-energy construct capable of boosting task-relevant schemes not sufficiently boosted by other metaconstructs is described. Age differences in the ability to deal with task complexity are attributed to developmental differences in this capacity. A priori, the theory was used to assess the demands of a discrete motor task and to predict: a.) the minimal age necessary to integrate the task, and b.) individual differences associated with efficient task integration in children above the minimal age. Empirical data supported

the predictions.

A neo-Piagetian Theory of Constructive Operators: Applications
to Perceptual-Motor Development and Learning.

The first section of this paper outlines Pascual-Leone's Theory of Constructive Operators with little attempt to make applications to Motor Behavior. This approach is taken to illuminate the theory's comprehensive and interactive nature. Although presenting the essence of the theory, this review is a condensation of Pascual-Leone's more extensive treatments (Pascual-Leone, 1970, 1976; Pascual-Leone, Note 1, Note 2; Pascual-Leone & Goodman, Note 3). Subsequent to this overview, application to motor behavior will be made via a discussion of empirical data.

As a neo-Piagetian theory it relies on Piagetian constructs as a foundation. However, unlike Piaget's structural theory which adequately predicts the ontogeny of behavioral capabilities; this process-structural theory has evolved to both explain and predict the temporal unfolding of behavior. Portrayed in the context of a single theory are mechanisms to account for learning, development and critically, the interaction of these two processes.

The theory of constructive operators is highly compatible with contemporary empirical work on cerebral organization, neurophysiology, cognitive styles, memory and attention (Pascual-

Leone, Note 1). In fact, one the major appeals of the theory is that it provides a consistent framework from which to view these diverse perspectives. The theory's predictive and explanatory powers stem not from mere eclectism, but rather a synthesis.

For the field of motor behavior a single comprehensive theory offers tremendous potential. As is readily evident at meetings such as these, much of the research on development or learning approach issues as if the two are independent processes. Furthermore, little or no consideration is given to the development or influence of individual differences. The current theory approaches the explanation and prediction of performance by considering learning and maturation as interactive processes which produce individual differences. The interactive nature of this theory provides for a much more integrated perspective of human performance, a necessity for the prediction and explanation of motor behavior.

Overview of the Theory

As a constructive theory the game of science (explanation and prediction) is approached by attempting to model or simulate the psychological system. Accordingly, the subject's psychological organism, i.e., the "silent organization" of his psychological machinery, is termed by metasubject (MS). Metasubjective

behavior is governed by a set of laws or rules proposed to be invariant across conditions and given metasubjective types. The theory is evaluated, extended or modified by testing this invariance.

The typical research methodology relies on a process of rational reconstruction, where, in the role of an ideal observer, the experimenter uses the medium of the theory to assess the metasubjective demands of the task. A similar ideal-observer task analysis is found in the work of computer simulators such as Newell and Simon (1972) and the study of artificial intelligence by Minsky (1975) and Papert (1973). Based on the assessment of task demands, predictions can be made and tested with respect to given subject populations' (i.e., metasubjective types) performance on the task.

Metasubjective processes are conceived as being hierarchically organized in two functionally and structurally different, interacting systems. The First level is constituted by situational-specific constructs, organismic schemes, which apply on the input to categorize or modify it; the second level is constituted by situational-free metaconstructs (organismic factors) which apply on the first level schemes (not on the input) to temporarily increase their potential of applying.

Figure 1
about here

Schemes, are defined as "an organized set of reactions which can be transferred from one situation to another by assimilation of the second to the first." (Piaget, 1969). As such they represent the perceptual, motor, affective and cognitive activities available to a given subject. All schemes consist of at least two components: a releasing component (rc) and an effecting component (ec) (see Fig. 1). The rc of a scheme is a set of conditions which when matched to features of reality, increase the activation weight of the scheme, the resulting activation weight of a given scheme represents its disposition to apply.

The ec of a scheme represents the consequence of its application, i.e., the set of effects the scheme reflects. Figurative schemes assign meaning (perception, imagery) to the input; whereas, operative schemes represent blueprints for internal or external actions. Higher order schemes termed executives, contain the metasubject's representation of task (any purposeful or goal-directed performance) instructions and the corresponding plans for solving the task.

Certain schemes may contain a third or terminal component

which either marks situational moments when the effecting component is discontinued and/or represents the situational state ultimately brought about by the schemes application (these schemes or "fluents" are described more extensively in Pascual-Leone, 1976).

Figure 2

about here

The field of activation depicted in Fig. 2, represents the schemes which are activated at any given moment, i.e., schemes in which at least some of the conditions in the releasing component are met. Not all schemes in the field of activation will, however, produce the subjects performance: only those schemes which are compatible and collectively produce the highest total activation weight will determine the response (this process Pascual-Leone calls the principle of Schematic Overdetermination of Performance or SOP, Note 1).

Second level constituents of the metasubject are situational-free metaconstructs or scheme boosters which by applying on schemes, increase their activation weights. That is, they indirectly shape behavior by influencing which schemes or clusters of schemes will apply. These constructs are crucial as they

provide an explanation for the human ability to generate "novel" behavior (i.e., override the cue function principle which accounts for activation weights and scheme application).

The A operator or Affective Factors can be situation-bound in which case they are a special sort of scheme, or situation-free in which case they correspond to motivational general arousal. General arousal functions as a multiplier or activation weights (Pascual-Leone, Note 4). Since multiplying activation weights would initially make dominant schemes more apparent, it would facilitate performance. However, continued multiplication of activation weights would ultimately favor the more weighted general schemes (as opposed to more task specific), thus, as in the Inverted-U Hypothesis (Duffy, 1962) result in a decline in performance.

In any goal-directed behavior the metasubject is motivated and monitored by a cluster of affective schemes which could vary in content from instinctual drives to specific feelings, affects and emotions. These schemes boost and bring to dominance an executive scheme which is functionally consistent with the "purpose" or "directive tendency" of that affective scheme (e.g., avoid anxiety-producing situations, become aggressive when frustrated).

The F factor represents two types of field effects: sensorial

$\underline{F}$ (F_s) corresponds to the saliency of cues, which is done to the nature of the stimulus (e.g., magnitude, intensity) and/or the innate characteristics of the receptors. $\underline{F}_s$ therefore corresponds to the psychophysical properties of the stimulus, adding $\underline{F}$ weight to schemes according to sensorial salience of the cues. Processing $\underline{F}$ corresponds to Piaget's field effects and figural factors (Piaget, 1969) or the S-R compatibility factor of learning researchers (Fitts & Posner, 1967). $\underline{F}_p$ applies on the field of activation to boost the activation weights of scheme clusters thereby bringing about response resolution or performance closure. The Mueller-Lyer and Witkin's Embedded Figures Test readily demonstrate this effect.

In the theory, $\underline{M}$ is defined as a limited amount of mental energy which can be used to boost task-relevant schemes not sufficiently boosted by other metaconstructs. Mobilization of $\underline{M}$ energy and the choice of schemes is under the direction of the executive scheme. In the context of human information processing theories, $\underline{M}$ is functionally analogous to a "rehearsal function" (Atkinson & Shiffrin, 1968; Bernbach, 1970) which can serve a "working" or an "active short-term memory (STM) function" (Hunt, 1973; Newell & Simon, 1972) - active because, in addition to the rehearsal function, it has an operating or computing function. However, unlike other current STM notions, the $\underline{M}$ construct is not

strictly speaking, a space (memory), rather it is a function which applies onto the subject's repertoire of schemes to increase their activation weights.

In accordance with Stroud (1955), Pascual-Leone (Parkinson, 1969) views time for human subjects as being divided into discrete chunks, referred to as "psychological moments". The M-demand of a task in a given "psychological moment" is the maximum number of discrete items of information (figurative schemes) and/or plans for action (operative schemes) that must be simultaneously activated, i.e., processed in parallel. Additionally, the number of "psychological moments" that must sequentially or serially attend to the task, contribute to the task of M-demand. In tasks, if either the M-demand in a given psychological moment or the number of psychological moments to be serially processed, exceeds the subject's M-capacity, the task cannot be successfully accomplished.

For children whose cognitive development is normal, M-capacity has been demonstrated to increase linearly with age (Case, 1972, 1974; DeAviala, 1974; Pascual-Leone, 1970; Scardamalia, 1977; Toussaint, 1974).

Table 1
about here

The left column of Table 1 contains the different values taken by M developmentally. As is evident from the table, M has been divided into two parts: the constant e and the developmental variable k. The constant e represents the M energy necessary to weight or boost the subject's executive scheme and is assumed to be invariant across ages.

The developmental variable k corresponds to the maximum number of schemes which can be boosted (into application) by the M-capacity available to the individual. It should be emphasized that one's M-capacity (k) defines the number of schemes that can be boosted into simultaneous or sequential activation, exclusive of those facilitated by other metaconstructs.

C learning or Content Learning corresponds to what Piaget (1949) and Gibson (1955) call differentiation of schemes. Individual schemes always represent invariants (i.e., regularities, lawfulnesses for which the scheme stands) developed through experience. When experience fails to correspond to the invariants, the scheme will accommodate, i.e., modify itself to be in closer agreement with reality. This accommodation may occur through changing conditions in a scheme's releasing component or by adding or cancelling effects in the scheme's effecting component.

Through L learning or logical learning, recurrent patterns

of co-activation (simultaneous or sequential) existing among schemes tend to be reflectively abstracted into an L structure.

As Pascual-Leone states:

"The practical consequence of this L learning is that the metasubject comes to have articulated internal models of the patterns of co-activation of the subject's recurrent performance, models which can be cued by any of the corresponding scheme constituents. (Pascual-Leone, Note 1, p. 30).

Two fundamental and yet fundamentally different L structures are explicated. Through overlearning (repeated co-activation) the schemes involved become interlocked and incorporated into a structural chunk or L structure. By definition these structures are holistic analogue representations which do not readily afford change once initiated. As such these structures would be expected to control ballistic or preprogrammed movements.

Through the use of M energy task relevant schemes can be boosted into co-activation and subsequent L learning. LM's, the structures created by this process, are discrete (digital) mobile units which represent information about the functional interrelationships between the scheme constituents. Consequently, these structures are like multipurpose programs which when boosted by M energy under the monitoring of an executive scheme (high order LM structures), can be assembled in various ways to meet special task demands. Considering their functional proper-

ties, LM structures could underlie movements requiring feedback control. As may be evident, a functional similarity exists between these structures and Schmidt's schema (Schmidt, 1975).

It should be noted that the two types of L structures described are highly compatible with the recent work on cerebral hemispheric specialization (Galin & Ornstein, 1972; Gazzaniga, 1974; Milner, 1971). For right handed individuals, the right hemisphere is described as being holistic or literal in its processing of information (LC). In contrast, the left hemisphere is responsible for analytic or sequential activities (LM).

Since these functional properties develop independently it is not surprising that individuals often develop preferred modes of functioning. These modes of processing information or organizing behavior have been associated with the cognitive style dimension of field dependency (Witkin, 1965; Cohen, Berent & Silverman, 1973). Field dependency has been attributed to asymmetric development in favor of right hemispheric functions (LC's) (Pascual-Leone, Note 1). Individuals with this cognitive style typically have a low functional M-capacity, performing below age-peers on complex tasks or those demanding sequential processing (Eccles, 1968; Pascual-Leone, 1970; Case & Globerson, 1974).

In the context of the theory, two primary reasons are propo-

sed to account for field dependents' low functional M: a.) a relatively rich repertoire of LC structures and a strong F factor predispose these subjects to organize perceptions and actions in a holistic fashion. As a consequent, more of their M-capacity must be used to override these influences when tasks demand M boosting, and/or b.) these subjects have a relatively poor repertoire of executive schemes thus effective mobilization of M may not be possible.

At the other end of the field dependency continuum, the field independent subjects' characteristically abstract the functional relationships from a situation (creating LM's) contributing to their relatively high functional M-capacity (see Pascual-Leone, Note 1 for an extensive treatment of this topic).

Since these cognitive styles possess different metasubjective composition and organization, they represent examples of different metasubjective types.

Applications to Perceptual-Motor Learning and Development

The study to be discussed (Todor, Note 5) involves children (N=114) 5-12 yrs. of age and tests the theory's ability to predict and explain both between and within age group differences in motor performance.

The Figural Intersection Task (FIT) (Burtis, Note 6) and the Water Level Task (WLT) (Piaget & Inhelder, 1956) estimated

cognitive style (functional M). Equal M-capacity within age groups (Pascual-Leone's developmental levels) was verified via the Compound Stimulus Visual Information Task (CSVI) (Pascual-Leone, 1970).

Figure 3

about here

A modified Rho Task (Todor, 1975) was the motor task used (Figure 3). The subject's task was to respond to the light stimulus by moving the crank handle around to the bumper, let go, and knock the target down. This movement was to be performed as rapidly as possible. Prior to actually performing the task, children were required to demonstrate that they understood the task instruction and had the required schemes in their repertoire, by performing the task at a slow speed.

A Priori, the theory of constructive operators and the principles of constructive cognition were used to assess the task's M-demand. This analysis indicated the integration of the circular movement, the hand release and the movement to the target, to have the highest M demand. Figure 4 depicts the metasubjective strategy necessary for efficient task integration. Also depicted are strategies with lower M demands but resulting in less

efficient performance.

Figure 4
about here

Strategy (1), the most efficient, requires that three schemes be boosted into simultaneous co-activation. These schemes represent: a.) an operative scheme directing the move to the target, b.) a scheme representing knowledge that the hand is open, and c.) a scheme representing the location of the target.

Strategies (2) and (3) denote metasubjective plans where only two schemes are M boosted and the corresponding behavioral consequences. Strategy (4) represents by far the least efficient, where each phase of the task is performed under the monitoring of a separate executive scheme.

According to the theory it was predicted: a.) 5-6 yr. old subjects (M=2) lack the M-capacity to effectively integrate this task, b.) children 7 yrs. or older would have adequate structural M-capacities to integrate the task, however, their efficiency (and metasubjective strategy) would be a function of their cognitive style (functional M) and c.) as successive age groups' M-capacity increasingly exceeded the task demands, the limitations imposed by cognitive style would diminish.

During each of 30 practice trials, latencies were recorded for: Reaction Time (RT) - the interval between the onset of the light and the beginning of movement; Circular Time (CT) - the time taken to move through the circular phase and to hit the bumper; Pause Time (PT) - the length of delay caused by hitting the bumper; and Linear Time (LT) - the time from the end of the PT to knocking down the target.

Results

For each task components the means of the last five trials were taken to represent the final performance. These values were used in a Q type cluster analysis (average linkage and Euclidean distances) which forms groups of subjects with similar performance profiles. At the step in the clustering procedure where 10 clusters emerged, 87.7 per cent of the population fell into 4 clusters or performance typologies (Figure 5).

Figure 5
about here

The performance of subjects in cluster #4 was superior to all other clusters on all task components. Since, by comparison, this typology exhibited the best performance on both PT and LT, it was concluded that these subjects exhibited the efficient

metasubjective strategy (i.e., simultaneous mobilization of 3 units of M). Table 2 provides a breakdown by age group of the composition of this cluster.

Table 2

about here

The extent to which inclusion in this cluster is age-related (i.e., M-capacity dependent) is readily apparent. Clearly, this performance typology is achievable by only a limited number of 5-6 yr. old subjects. In this case, all three subjects were over 6 yrs. of age (6.17, 6.5 & 6.67 yrs.) and thus near the upper limits of this maturational level. Furthermore, two of these three subjects had WLT scores well above the mean for 7-8 yr. olds ($z=2.05$, $.675$). Additionally, their CSVI values were within one standard deviation of the 7-8 yr. olds and well above those for 5-6 yr. old subjects ($z=1.38$, 1.43). This strongly indicates they had M-capacities equal to 7-8 yr. old subject (M=3).

The third subject (age 6.17), while scoring above average for age-peers on the WLT ($z=.508$) and CSVI ($z=.546$) was comparable to the 7-8 yr. olds only on the WLT. Relative to others in cluster #4, the high PT and LT latencies for this subject

($z=1.62$ and $.835$ respectively) suggest he was on the fringe of the cluster (a point confirmed by the clustering tree). Conceivably, this subject's long PT allowed for sequential rather than simultaneous activation of the necessary schemes. Thus, it is concluded, as predicted, the M capacity typical of 5-6 yr. old subjects limits effective integration of this task.

Theoretically, to successfully integrate this task, 7-8 yr. old subjects would have to use their structural M-capacity maximally. In this study, all 17 of this age group who acquired the efficient profile, were characterized by having values at or above age-peer means on both measures of cognitive style. Thus, in this age group, the ability to deal with task complexity is a functional (metasubjective type) rather than structural (maturational) problem.

Since 9-10 yr. old children typically have structural M capacities equal to 4 units, only those who manifest a low functional M or are maturationally below their age level should fail to acquire the efficient profile. The five subjects in this age group exhibiting less efficient performance profiles were below age-peer means on the CSVI and at least one of the measures of functional M, hence, this prediction was supported.

In the 11-12 yr. old group, even the low functional M children acquired the efficient performance profile. This was expected

since they have a structural M-capacity equal to 5 units, sufficiently above the task demand to allow even those with low functional M to succeed.

In summary, consistent with the predictions of the theory: The developmental construct M has been demonstrated to limit a child's ability to perform complex motor tasks. Secondly, given sufficient M-capacity, the individual's metasubjective composition or type, will influence the ability to deal with task complexity. Metasubjective type being a function of the subjects learning or experience. Finally, as successive age groups' M-capacity increasingly exceeds the task M demand, the limitations imposed by cognitive style (metasubjective type) diminished.

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TABLE 1
PREDICTED M CAPACITY

PREDICTED MAXIMUM M (e + k)	PIAGET'S SUBSTAGE	CHRONOLOGICAL AGE
e + 2	Last substage of pre-oper- ational period	5-6
e + 3	Low concrete operation	7-8
e + 4	High concrete operation	9-10
e + 5	Substage: intro. to formal operation	11-12
e + 6	Low formal operation	13-14
e + 7	High formal operation	15-16

TABLE 2

Age Group	Attainment of Mature Profile
11-12	100% (n = 17)
9-10	79% (19 of 24)
7-8	40% (17 of 43)
5-6	10% (3 of 30)

Figure Captions

Figure 1. Schemes and their constituents.

Figure 2. Constructs of the theory of constructive operators.

Figure 3. The Rho Task.

Figure 4. Meta subjective analysis of Rho Task integration.

Figure 5. Primary performance typologies on Rho Task.

SCHEMES

Releasing component (rc) →

A set of conditions which, when matched to features of reality, increase the activation wt. of the scheme.

Effecting component (ec) ---→

Carries the meaning of the unit; set of effects the scheme reflects.

Terminal component (tc)

Figurative schemes

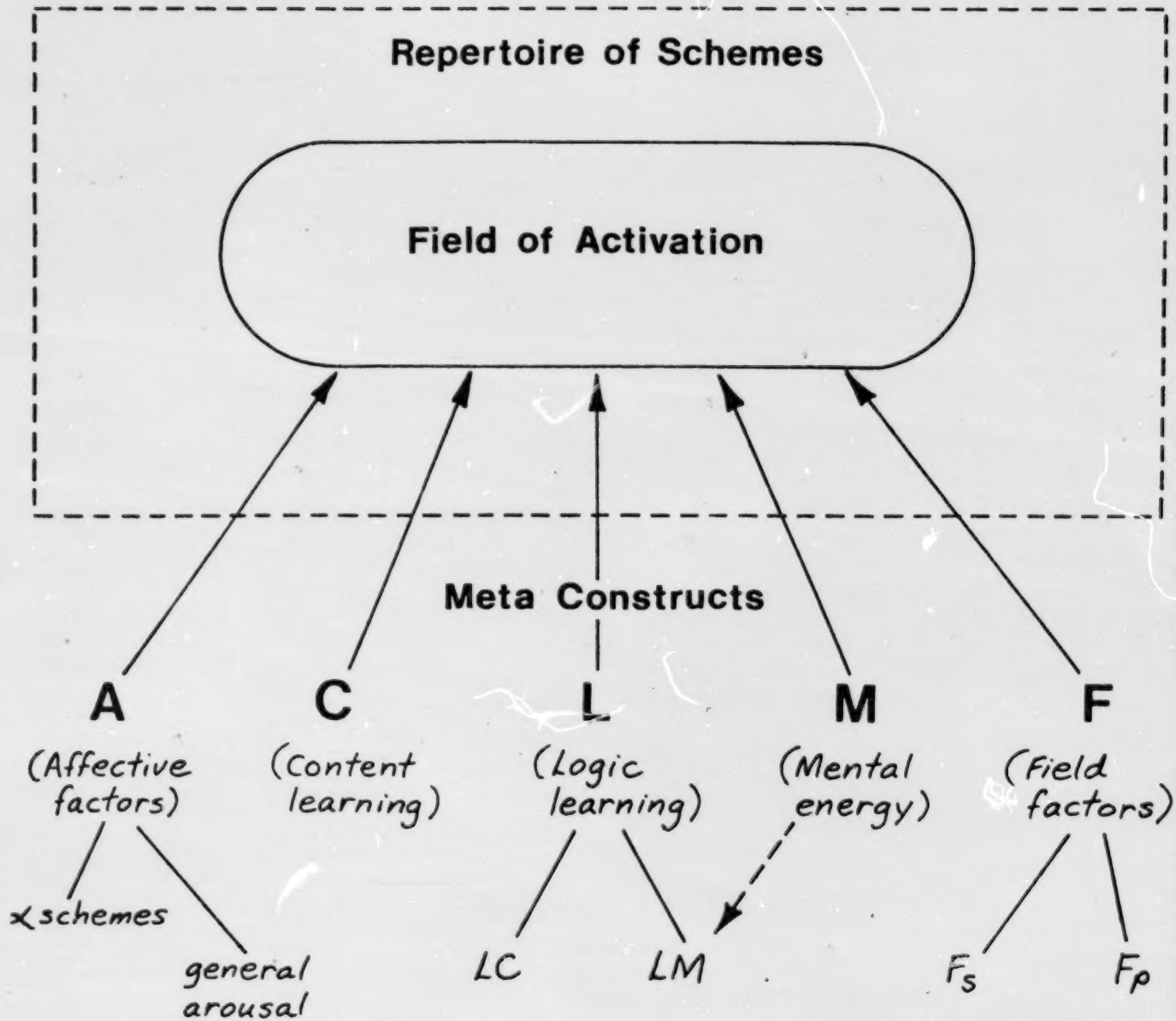
Meaning assignment
perception, imagery, etc.

Operative schemes

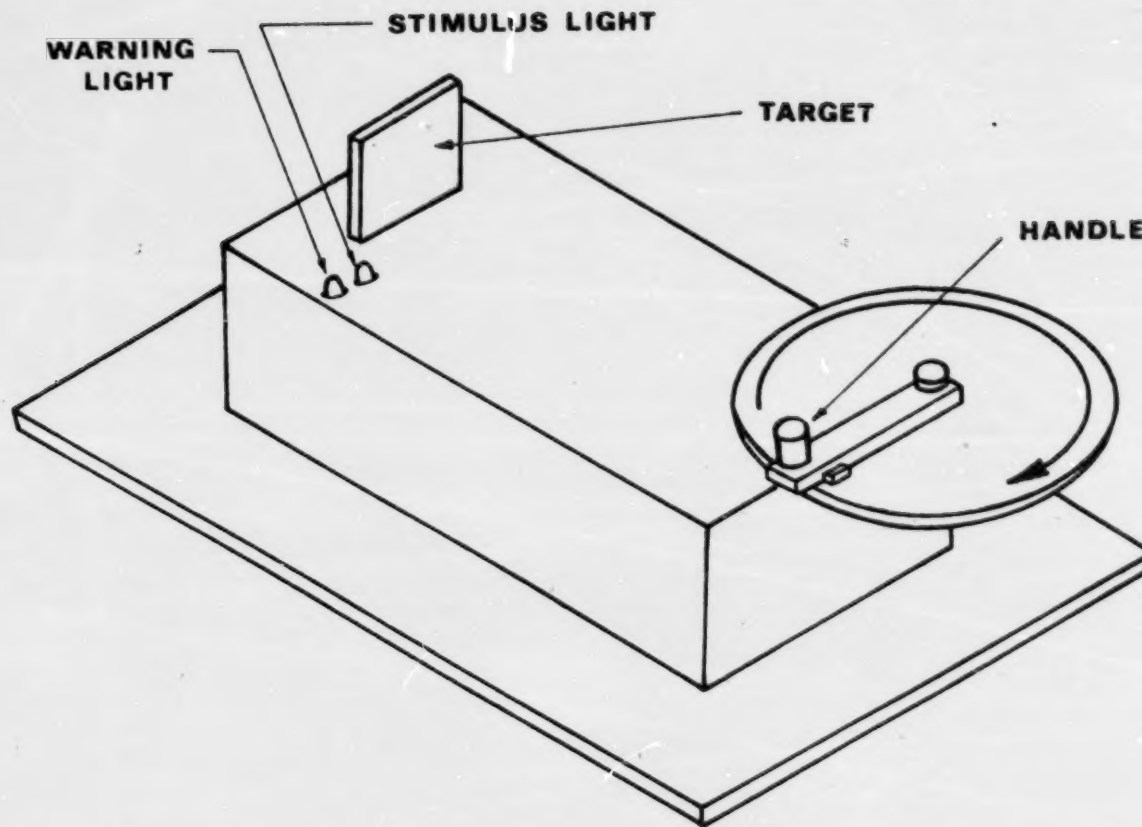
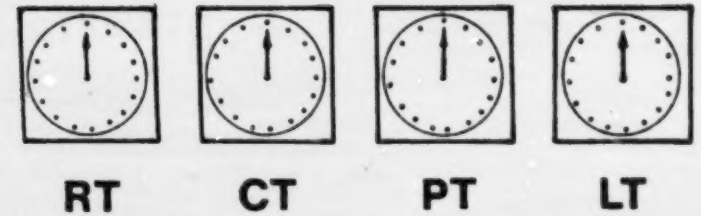
Blue prints for internal
or external action.

Executive Schemes

Higher order schemes; contain the MS representation of task instructions and corresponding plans for solving the task.



THE RHO TASK



Metasubjective Analysis of Rho Task Integration

(1) $\mathcal{E}_I, \dot{\Psi}$ Move to target # Open hand,
Target

MOST EFFECTIVE
TASK INTEGRATION,
FAST PT AND LT
M demand = 3

(2) $\mathcal{E}_I, \dot{\Psi}$ Move to target # Open hand

LEADS TO RELATIVELY
FAST PT BUT SLOW LT
M demand = 2

(3) $\mathcal{E}_I, \dot{\Psi}$ Move to target # Target

LEADS TO SLOW PT AND
FAST LT, RELATIVE TO (2)
M demand = 2

(4) $\mathcal{E}_I^1 \quad \mathcal{E}_I^2 \quad \mathcal{E}_I^3$

CHAINING OF EXECUTIVES
LEAST EFFECTIVE
 $\mathcal{E}_I^1$ = ROTATE
 $\mathcal{E}_I^2$ = OPEN HAND
 $\mathcal{E}_I^3$ = MOVE TO TARGET
SLOW PT AND LT

$\mathcal{E}_I$ - Executive scheme "Go to target" activated
upon contact with bumper

$\dot{\Psi}$ - Operative scheme

- Parameters (figurative schemes)

